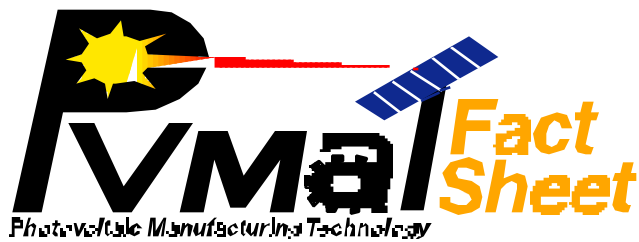


High-Throughput Manufacturing of Thin-Film CdTe PV Modules

Highlights

- Reduced module-manufacturing costs by 78%
- Increased production capacity by a factor of 4
- Cut labor costs for operating deposition system by 70%
- Produced 8 ft² module with 9.1% aperture efficiency—best among thin films

This Solar Cells, Inc. project is part of a 1995 solicitation of PVMaT—a cost-shared partnership between the U.S. Department of Energy and the nation's PV industry to improve the worldwide competitiveness of U.S. commercial PV manufacturing.



Solar Cells, Inc.

Goal

The goal of Solar Cells, Inc. (SCI) under this PVMaT solicitation was to reduce manufacturing costs while increasing module performance. Specific objectives were to:

- reduce module production costs on its high-throughput, thin-film cadmium telluride (CdTe), module manufacturing line
- increase module performance
- provide the groundwork for expanding commercial production capacities.

Background

SCI is developing CdTe modules for power applications. CdTe thin-film material will likely meet the goal of making PV competitive in large markets. This material is amenable to inexpensive mass-production techniques. And CdTe modules it are stable and efficiently convert sunlight to electricity.

Technical Approach

SCI's deposition process—an automatic, continuous feed, in-line approach—is very promising for low-cost module manufacturing. The process starts with a 5-mm-thick sheet of soda-lime glass coated with a transparent conducting oxide. The glass, which serves as a superstrate for the module and is typically 60 cm x 120-cm (24 in. x 47 in.), is loaded into the deposition system through a load lock. Glass sheets may be loaded one at a time or may be connected for continuous feed.

After loading, the glass enters a vacuum chamber in which a thin film of cadmium sulfide (CdS) is coated on the glass. The glass continues into a second chamber in which a thin film of CdTe (the absorber layer) is deposited with a technique known as high-rate vapor transport.

After the semiconductor-coated superstrate exits the system, it is treated with a cadmium chloride vapor. It then goes through a proprietary process for final module preparation. This includes patterning the thin films with

laser scribing; metallization, in which nickel-aluminum contacts are deposited on the back of the module; busbar application, in which thin metal ribbons are attached to the busbars and brought out through a hole in the cover glass; and encapsulation, in which the superstrate is laminated to a cover glass using ethylene vinyl acetate. Finally, ribbons are terminated in a connector molded directly to the cover glass.



This coating line can process 1400 superstrates a day at 100% yield.

The typical result is a 58-watt, 65-volt module intended for grid-connected applications. The process may also be used to make modules with sizes and power ratings suitable for remote or stand-alone uses.

Results

This project's impressive results include a four-fold increase in throughput and a 78% decrease in module production costs. These results were achieved by changing the deposition process from batch to continuous and by improving the deposition equipment. Consequently, SCI expects to be routinely making stable, 10%-efficient modules for less than \$3 per watt by 2000.

From Batch to Continuous

Before this project, SCI used a batch deposition process in two senses. First, a single glass superstrate was loaded into the system, coated with CdS and CdTe, and unloaded. Second, the source materials for the CdS

and CdTe layers were batch loaded into the deposition system by placing them over the substrate. As a run progressed and the source material was depleted to an unsuitable level, the run would be stopped to replenish the material. Also, system parameters like pressure and temperature would need adjustment to maintain the deposition rate as source materials diminished.

Because of new deposition components and a new design, the process is now continuous, with the ability to constantly replenish source materials and steadily process glass sheets. The system also uses an on-demand feature that allows the heating, vacuum, and conveyance subsystems to be decoupled from the coating subsystem: the operator can turn the coating on when a substrate reaches the deposition zone, allowing the system to reach steady-state temperature and pressure before deposition begins. The result is uniform deposition and high-quality semiconductor layers.

Improving Equipment

Improvements to all the deposition equipment have helped SCI increase throughput. The upgraded system can deposit CdS/CdTe layers on a 60-cm x 120-cm glass sheet in 30 seconds. This is 20 times faster than before the improvements and as much as 600 times as fast as competing processes.

The primary mechanical upgrade was adding load locks on the entrance and exit of the system to decrease vacuum pumping time to less than one minute. Capacity was improved because the locks allow multiple superstrates to be introduced into the system, decreasing the cycle time (i.e., the elapsed time between loading and unloading a superstrate) from 10 minutes to 2.5 minutes. The load locks also improve process stability: the deposition zone remains at the target process pressure as superstrates enter and exit the system.

The new system also uses better control mechanisms. The manual controls were replaced with a programmable logic controller, and the system runs automatically with no input from an operator except to load and unload superstrates. During a 100-plate run, one person operated the system at a cycle time of 3 minutes. Labor is reduced by 70%, and operator-caused process variability is eliminated.

Heating systems were also upgraded, with the original heaters being replaced with covered elements. This not only increased the power density of the heaters, but also improved their lifetime.

Validating the Product

SCI has installed more than 50 kilowatts of thin-film CdTe modules, with an average total-area efficiency exceeding 6.75%. These installations have shown reliable performance at or above system ratings. A champion 60-cm x 120-cm module was measured at 61.0 watts—or more than 9.0% aperture-area efficiency.

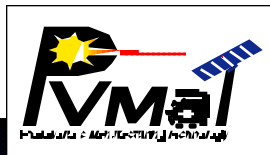
As part of its validation, the product was installed at several sites, including a 25-kW installation at Edwards Air Force Base in California. The project confirms that proprietary methods for making the support structures, and making, encapsulating, and connecting the modules reduce costs by more than 40%—compared to pre-PVMat methods. Most of this reduction results from using frameless panels and from replacing the junction box with a pigtail (i.e., pair of twisted wires).

Another installation, at Toledo Edison in Ohio, is a 14-kW grid-connected array. SCI also installed a 10.8-kW array at the PV Utility-Scale Applications demonstration site in Davis, California.

ES&H Issues

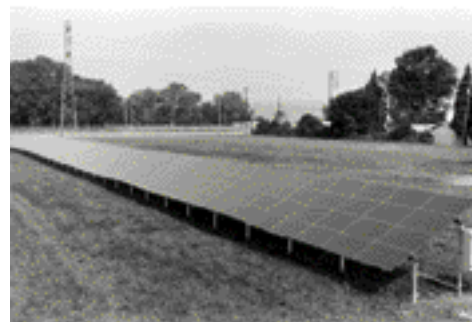
Environmental, safety, and health issues accompany the production, deployment, and disposal of CdTe modules. SCI had outside agencies and consultants conduct safety and health audits of the manufacturing facilities. Consequently, plant risks have been mitigated and eliminated.

Environmental efforts focused on minimizing waste and on reclaiming and recycling material. This work, begun under SCI's PVMat subcontract, is being commercialized with the support of a \$925,000 Small Business Innovative Research subcontract. The goal is to develop and commercialize a full-scale reclamation and recycling process targeted at CdTe modules.



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PVUSA installation.

Company Profile

Solar Cells, Inc., is now called First Solar. In 1999, First Solar, LLC, a joint venture between Solar Cells, Inc. (SCI) of Toledo, OH, and True North Partners of Phoenix, AZ, was created to facilitate the marketability of state-of-the-art CdTe technologies developed by SCI. This venture plans large-volume manufacturing—as much as 80 MW per year—of thin-film PV modules.

The company was founded in 1987 to develop and operate a continuous, automated manufacturing system capable of producing PV modules at a competitive cost for use by electric utilities; and to install solar-electric generating systems for grid connection, as well as for stand-alone uses. First Solar offers a variety of complete CdS/ CdTe production lines and plate finishing lines—for 1 kW/h, 2 kW/h, or 3 kW/h.

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